

The Universe with an Effective Discrete Time (II) *

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Abstract

The mechanism for triggering the universe inflation and its sharp exit could be that at very early periods the time variable was discrete instead of smooth, defining a new transplanckian time physical scale. Alternatively, and perhaps equivalently, it could be the consequence that the metrics of the early universe was a strongly concentrated gravitational coherent state with very high frequency oscillations, allowing local pair creations by a generalisation to gravity of the Schwinger mechanism, perhaps by creation of black holes of masses superior to the Planck scale. The lattice spacing between two clicks in the discrete time picture corresponds to the inverse frequency of the gravitational coherent state in the other picture. In both cases, a much lower time than the Planck time might represent a new fundamental scale, which possibly gives a new UV regularised type of physics. To make a possible rough estimation of the pair production probability, we propose that the oscillating coherent state metrics that reproduces this very early geometry minimises the Einstein gravity action coupled to interacting 1-,2- and 3-forms. Part of our intuition relies on a condensed matter analogy with laser-induced superconductivity. An independent section suggests that the new physical time scale we introduce for the Markovian discret time of the pre-inflation epoch can be identified with the stochastic time one uses for standard quantisation in the post-inflation limit. In the pre-inflation phase its discreteness is the observable driving force for the universe evolution, while in the post inflation phase it becomes unobservable and it can be effectively replaced by the continuous time coordinate of standard quantum field theory.

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1 Introduction

Unknown quantum gravitational physics exists at an age of the universe of the order of magnitude of the Planck Time $\tau \equiv \sqrt{\frac{\hbar G_F}{c^5}} \sim 10^{-44}s$ and earlier. According to current estimations, its effects might last till an age as late as $\sim 10^{-32}s$ and for a good fraction of the epoch of the cosmic inflation.

In the current phenomenological inflation model, the space expands with an ultra-fast exponential pace, between a time that is often estimated to be $\sim 10^{-36}s$ till a time between $\sim 10^{-35}$ and $\sim 10^{-32}s$. Such time scales are very large when counted in Planck units. The inflation wave propagates at a speed that is significantly smaller than the speed of light, therefore we can observe at the boundary of our past light-cone only a fraction of the Universe history. When one builds a model for the inflation, a strong constraint is the observed isotropy of the thermal fluctuations of the CMB.

After the end of inflation, and a very sharp decrease of the cosmological constant, the universe expands at a much less accelerated rate following the dynamics of the current elementary particle standard model (or its possible variations) with a very small value of the cosmological constant. In this regime, the classical Einstein theory describes well enough the gravitational effects for the cosmic evolution and one can understand the quantum effects by using the mathematically consistent standard model of electroweak and strong interactions.

Nowadays, the measured cosmological constant is very small. Before and during the inflation, its effective value was much bigger. This note is about an attempt to physically explain what may have induced this transition. We will propose a possible microscopic explanation for the huge fluctuations that triggered the inflation.

The obvious difference between very early times and the present time is that intervals of the order of (or shorter than) the Planck Time τ are unobservable in the post-inflation universe, the opposite of what must happen in the transplanckian universe. Nothing ensures us that time could be described by a smooth and continuous variable in very early times. We will in fact suggest that the time evolution was perhaps discrete, by steps of τ or another much smaller time, which would define a new quantised time scale. We will propose that this could be an explanation for the triggering of the inflation, naturally giving a strong change of the vacuum energy due to fluctuations, that is, a most likely irreversible change in the value of the cosmological constant. In fact, we propose that the duration of elementary gravitational phenomena for the period of the inflation is a very small fraction of the Planck time of order 10^{-15} , by analogy with the known ratio $\sim 10^{-15}$ between the typical time scale of a microscopic chemical reaction and the length time of a macroscopically observed chemical reaction. The value $\sim 10^{-15}$ also applies to the ratio between the duration of elementary reactions that occur when liquid water ices and the duration of the glaciation of a macroscopic quantity of water. Analogously, when one consider macroscopic ferromagnetism transitions, the estimated time of an elementary spin flip is $\sim 10^{-12}s$. Therefore we propose the relevance of a discrete time that clicks by steps of $\sim 10^{-15}\tau \sim 10^{-60}s$, a new fundamental microscopic time scale that we assume for microscopic reactions at the scale of the Planck time, and we

consider τ as an already macroscopic time unit in the early phase of the universe. We also propose that the cosmological constant can serve as an order parameter that determines in which phase the universe physics description stands, either with an observable discrete time behaviour or with an effective continuous time that averages smoothly over a large number or iteration of the Markov steps.

Perhaps equivalently, and more realistically to reasonably hope to do concrete computations, we could keep a continuous smooth time, but propose that, when the universe was very small, the gravitational field metrics was a highly concentrated singularity free coherent state with an ultra fast frequency $\sim 10^{60}Hz$, filling either the whole universe or just a localised region of it. Such a field could be cause of the huge vacuum fluctuations that one often expects to redistribute the energy in a variation of the curvature as well as in the energy momentum tensor of non negligible amounts of matter. The mechanism can take the form of generalised Schwinger effects (adapted to the case of a strong oscillating gravitational field) that would create pairs with masses of order the Planck mass, maybe under the form of black holes. The fate of the latter is to decay eventually in ordinary elementary particles. The end of inflation is then the global evolution from the former coherent state to a weakened one filled with more and more matter. The transition is irreversible because it is accompanied by an increase of the size of the universe and a dilution factor with matter creation, such that, altogether, the value of the cosmological constant decreases rapidly enough. To describe microscopically what triggers this evolution, one can perhaps only use the microscopic content of the standard gravity coupled to forms and to the standard model of the electroweak and strong interactions.

Both cases, either a genuine discrete time or a rapidly oscillating background gravitational coherent state, could equally well explain the transition between a large and a very small value of the cosmological constant.

An important difference between our proposal and other ones in a static DeSitter space, (see for instance [7][9]), is analogous to that existing between pair creations by the Schwinger mechanism within a high frequency resonant cavity [5] and within a static condenser. It provides a much more dynamical frequency dependent factor to trigger vacuum fluctuations. In fact, in any given QFT, one expects that any given coherent state that defines a vacuum has always a non-zero probability to decay into another coherent state, which defines a new vacuum, with a shower of particles that enforces energy conservation. The quantitative details obviously depends on the theory. To possibly get some concrete realisations, we will in fact propose an Einstein action coupled to a set of 1-, 2- and 3-forms, all these fields vibrating at the same or comparable super-fast frequencies at early times, at least in a local part of space. Getting non-singular solutions is preferable because one expects that the small time scale that one uses can be seen as an ultraviolet cutoff. The computation of such solutions for the metrics is a priori a feasible task, using appropriate boundary conditions. For instance, having an early space with a toroidal structure S_3 may facilitate the existence of time oscillating solutions. It is not yet obvious that we can have relevant oscillating solutions when the universe has strong spatial symmetries. There are interesting indications that non standard geometries occur for certain couplings of gravity to gauge theories, as for instance in [8] and references therein. There are abundant descriptions of time dependent geometries in the literature

but it is still unclear if even one of them is appropriate for favouring the scenario presented here. As we just say, the hypothesis of a discrete time provides a physical scale for an absolute ultra-violet cutoff for all generality solutions, thus one needs to exhibit *non-singular* solutions of general relativity to mimics the effect of a discrete time. Physically, one can think to such solutions as sorts of gravitational laser beams, which can be created spontaneously because of the non-linearity of general relativity equations coupled to some matter fields.

When solving the geometry of the space, solutions that exhibit some aspects of the DeSitter space are desirable but they must be time dependent. Moreover, some of their perturbative excitations around their primary oscillations must have a long range propagation in the part of their future light cone, as one observes in the measured CMB. The duration when one has strong enough oscillating gravitational fields that give a big enough number of pair creations can be very short, but the frequency of the oscillations should be extremely high, giving a new time scale much smaller than the Planck time. and thus an energy scale much higher than the Planck mass. Our simplifying hypothesis is that that the coherent oscillations are fast enough to produce pairs of black holes, with masses of the order of magnitude of the Planck mass, maybe rescaled by a scale factor $\sim 10^{15}$, which relates microscopic effects to macroscopic ones, that is, masses of order $\sim 10^{35} \text{Gev}$.

The mechanism is neither in contradiction with the phenomenological explanation of the CMB by the amplification of perturbative quantum fluctuations within a DeSitter background nor with the reheating phenomena when particles are created in abundance, The coupling of a 3-form gauge field to gravity with Chern–Simons couplings involving propagating 1- and 2-form gauge fields is perhaps an enhancement factor for getting such time dependent early universe backgrounds, with appropriate time-depending geometries. It might be even sufficient to have a local and big enough bubble of the early universe with such an oscillating behaviour, since we can only observe a fraction of all past events, the rest being outside of our past light cone.

Let us also contemplate some of our present experimental knowledge about time. Our best atomic clocks work at the scale of *QED* processes for atoms and allow us to detect time intervals down to 10^{-18}s . This is the present smallest time scale for which one has directly verified the hypothesis of a smooth and continuous time variable. Having a continuous time down to the Planck scale is not in contradiction with all current astrophysics experiments. The LHC, our strongest microscope, uses elementary particle tools instead of atomic tools. Using the tested Lorentz invariance, it gives us a test for shorter smooth time intervals that correspond to form factors with a scale $10^{-17} \text{cm} \leftrightarrow 10^{-27} \text{s}$. This accuracy is completely out of scale as compared to the smallness of the Planck time. In fact, testing the hypotheses of continuous smooth time and space variables are quite different subjects, although they appear as naturally related, assuming Lorentz invariance. The latter has been well verified at the LHC scale, but it can always be questioned at much smaller space and time scales, which is a justification for our proposal of a new time scale, much smaller than the Planck time.

Therefore, given the minimal scales of space and time that have been experimentally reached, there is no contradiction for having theories with a smooth time variable in our

epoch and a discrete discrete one in the early ages with a lattice spacing quite small in Planck units, in a regime for which we don't have yet a theory. Such a new microscopic time scale can also play the role of a physical ultraviolet cutoff, in a way that is possibly compatible with the hypothesis of asymptotic safety of S. Weinberg.

A possibly fundamental discreteness of time or a more conventional driving effect by a huge gravitational coherent state is allowed by the smallness of the very early universe and its enormous gravitational concentration and perhaps justified by the existence of the inflation.

In our scenario, it is not really important whether the time of inflation was before or after a date of order of the Planck time. The current ideology is that the inflation occurred after the Planck time. There is some fuzziness about the moments when the Markovian time we plea for could be *almost* approximated by a continuous time. This is an analogous difficulty as for describing what really often during some intermediary moments of a phase transition, for instance in ferromagnetism transitions that last for hours before reaching the magnetised form, while the duration of a spin flip is about $10^{-12}s$.

In fact, both scenario predict driven quantum fluctuations, materialised by avalanches of pair creations at high frequency that generalises the QED Schwinger mechanism. The description with no discrete time but with the embedding of the system in an oscillating vacuum is more conventional. It may justify in an easier way the non-uniformity of the CMB by the propagation of quantum fluctuations around this quasi-classical gravitational field from one phase to the other. The non-uniformity of the CBM can take various aspects, depending on the initial conditions and on the details of the propagation of microscopic transitions in a phase transition. Detailed computations of the propagation of these fluctuations for the transitions are maybe possible and can be very complicated, although one can do strong simplifying hypothesis, as one often does in condensed matter. On the other hand the scenario with a discrete time gets rid in an apparently easy way of the difficulties of singularities of classical and quantum field theories by providing from the beginning an physical ultraviolet cutoff.

In the present phase of the universe, such small time scales cannot be directly measured. We will in fact speculate that even if the Markovian time is still running but is unobservable, it can be mathematically identified with the stochastic time of stochastic time quantisation that is perfectly well suited to describe the present quantum effects. We suggest that the latter average over a huge number of very smooth Markov processes.

To try to illustrate the effect of a discrete time, we first describe a simple condensed matter example, where a laser beam possibly triggers superconductivity for a sample of matter where valence bands and conducting bands are adequately organised *. Then we will try to establish a dictionary to extend the idea for the effect of a discrete time on the evolution of the Universe at early times.

Notice that the effects of non-linearity are surely an important ingredient for triggering strong transitions of the vacuum.

*More fancy mechanisms can be found in the literature for explaining high T_c transitions for superconductivity.

The non-linearity of the gravity theory makes very non-trivial the study of its coherent states, which should exist anyway, since we face a theory with infinite range. Since we don't know the quantum version of gravity, it is not possible to give the precise definition of its coherent states, except that they must be the quantum states that are as near possible from classical solutions while being possibly subject to quantum fluctuations, following the ideas of Schrödinger. This non-linearity might be the cause of the highly concentrated and rapidly oscillating gravitational fields that are maybe at the origin of the huge fluctuations that modify the vacuum and thus the value of the cosmological constant.

In the condensed matter example [4] that we will describe as an inspiration tool, there is also some non-linearity. As compared to the gravity case, the situation is somehow reversed. The coherent state of a laser beam is a solution of the linear Maxwell theory and the non-linearity lies in the (phenomenological) shape of the band structures of the irradiated matter sample, as well as in the laser apparatus itself. It is also known that so-called topological defects play an important role for the description of some phase transitions. This was shown in [2], with predictions that were checked experimentally by the discovery of new phenomenon in the hydrodynamic of some phases of Helium. The possible role of string theory defects has been widely discussed for early time cosmology, following the work of Witten [3].

The last section (that was not presented in an earlier version of this paper) concerns the idea we briefly mentioned above, that the new physical time scale $\Delta T \ll \tau_{Planck}$ we introduce for the Markovian discrete time of the inflation epoch can be identified with the stochastic time one uses for standard quantisation. It becomes physically unobservable (not to say confined) in the post-inflation limit, by definition of having a "phase transition" that freezes eventually the effects of quantum gravity. We don't discuss here possible effects that the new microscopic time scale $\ll \tau_{Planck}$ could help to uncover about Weinberg ideas of asymptotic safety and about the necessity of having a minimal length in string theory.

2 Discrete time versus driven coherent state microscopic effects, the condensed matter example

To understand the possible effects of a theory with a discrete time, we may rely on condensed matter considerations, where a laser beam, which is a powerful coherent state with a given periodicity $1/2\pi\omega$, can be used as "a discrete time reservoir", or "as a buffer for large energy fluctuations" to impose its pace to a system. Such a buffer is more subtle than an ordinary heat and/or particle bath. One then escapes the constraints of having energy scales that are governed only by thermal energy kT and chemical potentials μ in standard systems, when the standard Fermi-Bose distributions make so difficult the prediction of high temperature superconductivity. In fact, the possible effects of laser irradiation in condensed matter were foreseen as early as in the 70's in [1].

Condensed matter models with such a phenomenological periodic discrete time imply-

ing transitions have been recently considered. They involve the irradiation by a strong enough external laser beam over a well structured sample of matter with some conduction and valence bands. The whole apparatus is thermalised with an elementary heat bath that controls temperature. Having no irradiation, the standard Fermi-Bose distributions are actually rather restrictive for predicting strong transitions, especially superconductivity at not so low temperatures. On the other hand, an external intense laser beam with frequency ω introduces another energy scale $\hbar\omega$ and can simulate a driven discrete time behaviour by steps of $1/2\pi\omega$. A refined shape for the periodic pulses of the laser can make the situation even more interesting, by introducing other time scales and thus other energy scales. The whole system simulates macroscopically an effective non-conservation of the energy, although energy is conserved at the microscopic level when one computes all the photon exchanges between the laser and the matter.

In these examples, a given order parameter for the irradiated matter can drastically change because of predictable macroscopic fluctuations in the energy. As foreseen in [1], one can invent and possibly trigger new exotic phase transitions, because, as already said, one avoids the constraints of genuine Fermi or Dirac statistics. For instance, the resistivity of an irradiated sample can change sharply, as if there was a phase transition. When time is discrete, one basically escape the difficulty of getting stable Cooper pairs at high temperature because the observed energy is effectively not conserved between two successive times : the measured energy of the sample can jump by possibly large quantised and uncorrelated gaps. Thus non trivial fluctuations can emerge that can drastically change the aspect of the irradiated domain, for instance by putting in a stationary way all electrons in the conducting band. Then, the standard temperature energy scale kT just becomes an external parameter. The energy quanta that allows the huge transitions is $\hbar\omega$ rather than kT , where ω is the frequency of the coherent beam. One can thus theoretically stabilise e.g. Cooper pairs at rather high values of the temperature. It is thus suggestive to call an irradiating beam as a “discrete time reservoir”, giving a sort for equivalence principle between a driven period force by irradiation by a coherent state and genuine discrete time effects.

Of course, in condensed matter, the discrete time is just a formal but convenient mathematical trick for a macroscopic description within a statistical model. We know in this case that the underlying microscopic physics is the well mastered quantum electrodynamics with a continuous time. The behaviour of order parameters such as the conductivity is driven by the effect of this effective discrete time intervals cadenced by the frequency ω of the external laser (or the period between its pulses, or, even more subtlety by some combination between the pulse width and their periods). The energy conservation is globally ensured by the power consumption of the laser that balances the property that (almost) arbitrary numbers of photons of the same energy $\hbar\omega$ are microscopically continuously pumped in and out of the laser beam, ensuring the macroscopically observed effects of transitions due to the fluctuations that are inherent to a theory with a discrete time. This is the buffer strength of the laser that drives the effective discrete time behaviour.

For the sample that is irradiated by the laser beam, however, everything happens as if time is discrete, clicking by intervals of $1/2\pi\omega$. Then, between two clicks, energy is conserved only modulo integer numbers of quantas of energy $\delta E_{\text{elementary}} = \hbar\omega$. So,

between two successive times $n/2\pi\omega$ and $(n+1)/2\pi\omega$, the observer will measure that energy is conserved only modulo integer values of $\delta E_{\text{elementary}} = \hbar\omega$. In other terms, at any given possible observation time, the measured energy of the sample can be

$$E \sim E \pm N\delta E_{\text{elementary}} , \quad (1)$$

with no small bound on N . As a result, the behaviour of the sample can change and simulates a phase transition. For instance when it is traversed by an electric current, the Joule effect becomes completely different, leading possibly to a stimulated superconductivity, at any reasonable value of the temperature, possibly for values of the temperature T much larger than in the situation with no laser illumination. Of course the effect stops soon after one unplugs the laser, and the system comes back to its original state, as a sort of crunch. Notice that for the current that measures the effective resistivity, the existence of the laser beam is irrelevant, what only counts is the possible access to the appropriate conductivity band, independently of the microscopic mechanism that triggers this access. As for the observer who measures the resistivity, he can be considered as blind to the existence of the laser. If it is so, he might conclude to the existence of a discrete time.

The theory with a discrete time implies from first principles that the integer N can be as large as one wants. When one goes to the details, the standard energy conservation is recovered for not too big values of N and $\omega \rightarrow 0$ or $\hbar \rightarrow 0$, or more generally, $\hbar\omega \rightarrow 0$.

The smart theoretical case elaborated in [4] is when electrons are strongly and persistently expelled from a valence band to a conductivity band of a well built sample of matter, even for not so small temperatures, as long as the laser beam is activated. The curve in Fig. 4 in [4] shows the time evolution of the resistivity of the irradiated sample with a spectacular transition from a stable plateau to another stable one, with a rather quick evolution that is either oscillatory or damped, depending on the values of some parameters. The details for the shape of the transition are in fact irrelevant, the overall effect of having a transition being the same. This curve is very suggestive, showing an evolution of an order parameter that is quite alike the one one wishes for the evolution of the cosmological constant for the inflation epoch.

A relatively simple example of condensed matter with driven discrete time effects may thus lead to a model with very non-trivial consequences and non trivial changes of an order parameter. Notice also that the observer might ignore the existence of the laser and explore the system only using the Floquet theory about genuine discrete times, which has becomes popular in condensed matter.

We now pass to the gravity case.

3 Extension to Gravity at early times

How should we describe time intervals and time evolution in the very early universe ? In this epoch, nothing ensures us that we have a smooth behaviour for the time variable. Should we maintain the assumption that energy conservation works in the early universe

as it does when time translation invariance exists with a smooth time variable because of the Noether theorem ?

Here, we will assume that, at a very early time, say at least much before $\sim 10^{-32}s$, and maybe even much before the Planck time, the continuous time evolution must be replaced by the evolution in function of a discrete time coordinate, either fundamentally or effectively. There is the natural question whether Lorentz invariance is still present in this regime; it may happen that space is then either smooth or discrete to maintain its relativity with time.

We assume that when gravity was very dense everywhere, time was possibly discrete, with a yet undetermined theory, but some basic principles of quantum mechanics were still operating. They are: (i) the uncertainty principle between some variables and their conjugates ; (ii) the existence of coherent states for making the bridge between classical and quantum fields. These properties can be demonstrated in ordinary quantum field theory and quantum mechanics. For quantum gravity, with or without a discrete time, it is quite reasonable to assume that they remain true.

In the ordinary case of *QED*, the way coherent states can drive the system by microscopic interactions between photons and atoms is well understood. One can compute the rate pair creations by the Schwinger effect in intense laser beams (at least two face to face laser beams are needed to preserve the Lorentz invariance of a pair creation). Basically, one has the evolution between a given coherent state and another one, with a creation of matter. We will in fact assume a sort of equivalence principle in quantum gravity, between the effect of a fundamental discrete time and a forced time evolution by a periodic strong coherent state, a phenomenon that we suppose may have occurred in the conditions of the early Universe. The mass of the created pairs is assumed to be higher, and perhaps much higher, than the Planck mass, possibly under the form of black holes, whose further evolution remains to be thought of.

We thus suggest that simple predictions can be drawn, for the triggering of inflation, without doing too many model-dependent hypotheses. Eventually, one has to verify that the inflation effect triggered by a discrete time behaviour is compatible with the phenomenological description by the standard inflaton field, with an appropriate potential. From our point of view, the existence of an inflaton field is clearly not needed, although it gives a satisfying phenomenological description.

It is suggestive enough to state that when (i) the percentage of dark energy is very high and (ii) the size of the universe is very small, the enormously concentrated dark energy is nothing but the energy of a gravitational coherent state, which determines the size and the vibration of space. At this time, the universe is thus analogous to a resonant cavity. One can be less ambitious and consider only a bubble of the whole space, where the relevant fluctuations will occur, in particular the bubble that will be the whole past as seen from the light-cone past of an observer in the present epoch. It can drive huge fluctuations of the vacuum of the gravitational and standard elementary particles model, leading to the eventual production of ordinary and dark matter by the Schwinger effect, so that, effectively, the universe is driven toward a phase with a very small cosmological constant. Some of the vacuum energy of the gravitational coherent

state is in fact transformed into the energy momentum tensor of ordinary and dark matter, initially under the form of decaying objects with masses of the order of the Planck mass, in interaction with a thereby attenuated coherent gravitational state, given a significant decrease of the proportion of dark energy. One may ignore the exact details that occur all along the transition, which could follow various paths, analogous to those that occur when, e.g., ice melts into water in a few minutes, while, in comparison each step is done by minuscule increments of time of the order of that for chemical reaction $\sim 10^{-15}s$. In the case of the melting of the ice or the icing of liquid water, there are many possible paths for the propagation of the process. Eventually, the structure of ice becomes very simple, (by this I mean that its structure is not very far from that of a crystal). So, we may believe that the impressively simple isotropic shape and causal structure of the presently observed CMB and its phenomenological description by the inflaton model and a simple effective potential is one other wonderful example that nature often choses simplest mathematical tools for a macroscopic description of systems with a much refined microscopic structure.

Supposing that the uncertainty principle remains true, one predicts that there will be ordinary energy quantum fluctuations of the order of the Planck mass $M_{Planck} = \sqrt{\frac{\hbar c^5}{\hbar G_F}} \sim 10^{19}$ GeV. However, they are relatively extremely small, since the universe energy is certainly vastly superior to the mass energy of its nowadays existing $\sim 10^{80}$ nucleons. It is hard to expect non trivial transitions simply from such relatively small fluctuations, when one assumes that time is a smooth variable.

The hypothesis of having a discrete periodic time allows us to go further with not too many thinking. Effectively, since there is no way to go to intermediate times between $n\Delta T$ and $(n+1)\Delta T$, the energy is no more a conserved quantity. Rather, as a prediction of the quantised Floquet theory, when one measures the energy at these successive times, it is conserved, but only modulo integers numbers time the Planck mass (if it is the scale for the discreteness of time), that is

$$E_{universe}^{(n)} \rightarrow E_{universe}^{(n+1)} = E_{universe}^{(n)} \pm \mathcal{N}^{(n)} M_{Planck} \quad (2)$$

The value of the integer $\mathcal{N}^{(n)}$ can be big enough for a given value of n . When one applies this to a gravity theory with a discrete time variable, one sees that there is always the possibility of the needed vacuum energy fluctuation for triggering inflation. The needed time can be just a few units of the elementary time quanta or much longer. At very early times the time quanta we propose is $\Delta T \sim 10^{-15}\tau \sim 10^{-60}s$. In fact, after reaching a long enough time $(n+1)\Delta T$, the vacuum may be a state where the time can be described as a continuous variable, and the observed post-inflation regime using the standard model description can start. The proportion between the relative percentages of dark energy and matter energy, and thus the value of the cosmological constant will be changed after the transition. In our scheme most of the matter should appear by a generalised Schwinger effect in an oscillating gravity field. When the universe expands and becomes filled with more matter, dark energy gets diluted and it loses its coherence, so its influence on matter become much less important, apart from the classical gravitational attraction.

When the time becomes effectively a smooth variable, intervals as short as ΔT become

unobservable, the elementary processes last for much longer time than ΔT and the universe follows its slow evolution, as it is now, with a smooth time formulation. A reversing crunch looks hard to think of, once dark energy become more and more diluted, since the probability of fluctuations becomes smaller and smaller.

4 Estimating the gravitational Schwinger effect in the early Universe

We wish to be a bit more quantitative and try to estimate the rate of Planck mass pair production in a strong pure gravitational coherent state with very fast oscillations.

Our quantitative evaluation of the basic mechanism can only be very heuristic.

There has been numerous excellent papers using the DeSitter space for studying inflation scenarios with a cosmological term, for instance [7][9], although such spaces are basically instable and nothing can really move inside them. It has been realised that they may have a tendency to create matter by the Schwinger effect. The back-reaction of this phenomenon is a non-trivial subject. One understands that any classical field distribution is subject to instability, as emphasised decades ago by Pauli and Schwinger. However, we believe that the Schwinger effect of a static field is a too smooth effect to induce a decisive phenomenon such as the beginning of inflation. Coming back to the condensed matter electromagnetic-induced transition for superconductivity, we also understand that a laser with an appropriate frequency is more likely to trigger the phenomenon rather than a static condenser that can only provide a constant electric field.

The formula and reasoning of the production of pairs in time depending fields is explained in [5]. For high frequency colliding laser beams the probability of production of a pair in an electric field $\sim E \cos \omega t$ can be computed to be proportional to

$$\left(\frac{eE}{2\omega mc}\right)^{\frac{4mc^2}{\omega}}. \quad (3)$$

The Schwinger formula for the probability of pair creation in a constant static electric field E is

$$P \sim \exp - \frac{m^2 c^3}{eE}. \quad (4)$$

Both formula can be demonstrated microscopically within *QED* and one can interpolate between them. In the static case, the result boils down to the fact that the probability for creating a pair is the exponential of the ratio of two relevant scales: the mass of the threshold for creating a pair, and the work of the classical field on the Compton length of the particles to be pumped out of the vacuum. The formula must be completed by some perturbative infinite resummation in the case of oscillating fields [5]. The phenomenon is often computed as a vacuum fluctuation using the coherent state formalism of *QED*.

Let us very crudely give a possible estimation of the Schwinger probability for creating a pair of mass m (m is typically the Planck mass) in a Schwarzschild gravitational field far away from the horizon. The physical arguments is the following. In a sphere with mass M and radius R , the average value of the gravitational field is $|g| \sim GM/R^2$; For creating a pair of particles with mass m , the work on a Compton length is thus about $\frac{\hbar}{mc} \frac{GMm}{R^2}$. This quantity must replace $eE \frac{\hbar}{mc}$ in the *QED* Schwinger formula, so one gets:

$$P \sim \exp - \left(\frac{cR^2}{\hbar GM} mc^2 \right). \quad (5)$$

For $m \sim m_{Planck}$, this formula gives

$$P \sim \exp - \left(\frac{R^2}{L_{Planck}^2} \frac{m_{Planck}}{M} \right). \quad (6)$$

We are not so much interested by the static case. Rather, we prefer the option that the early Universe works as a resonant cavity with time dependent gravitational coherent states, whose frequency is much higher than the inverse Planck time. This corresponds to a fast oscillating geometry in general relativity. To get an estimate, we blankly extend the *QED* frequency dependent formula. With the same notation for the mass and radius of the universe, the gravitational analogous of the QED formula for creating matter pairs with masses m of the order of the Planck mass in an oscillating gravitational field can be reasonably assumed to be

$$\left(\frac{eE}{2\omega mc} \right)^{\frac{4mc^2}{\omega}} \rightarrow \left(\frac{GmM}{R^2} \frac{1}{\omega mc} \right)^{\frac{\omega_{Planck}}{\omega}} = \left(\frac{M}{m_{Planck}} \frac{L_{Planck}^2}{R^2} \frac{\omega_{Planck}}{\omega} \right)^{\frac{\omega_{Planck}}{\omega}} \quad (7)$$

That is, in Planck units for masses and lengths

$$P \sim \exp \frac{\omega_{Planck}}{\omega} \left(\log \frac{M}{R^2} + \log \frac{\omega_{Planck}}{\omega} \right) \quad (8)$$

When the frequency ω of the gravitational coherent state is big enough, with

$$\frac{M}{R^2} \gg \frac{\omega}{\omega_{Planck}}, \quad (9)$$

the probability of matter creation can be large enough for a time that is long enough to create the matter whose amount will decrease substantially the value of the vacuum energy at the requested rate, which depends on the value of ω . The scenario of a stable oscillating gravitational field seems therefore more appropriate for pair creations than a static one, which effect is very soft in comparison. Doing more concrete computations would be extremely useful.

5 Beyond the DeSitter case and the coupling to oscillating fields as an enhancement factor for pair production

The mechanism we invoke implies the existence of a fast frequency gravitational coherent state when the space was minuscule, which gives a new energy scale related to the fre-

quency by the Planck constant, even if the standard QFT is not applicable at such small scales of space-time.

Our hypothesis of a discrete time, (giving another scale than that of possible horizons) could be more realistically supported if we had at our disposal geometries with high frequencies time oscillations. For a simulation, one can think of replacing the static singularity of the Schwarzschild–DeSitter case by sources of very rapidly oscillating black holes. They might produce the needed high frequency gravitational coherent state for triggering the inflation, and then producing particles. Knowing the difficulty to get not oversimplified time dependent solutions of general relativity, we are in a difficult position to test the idea. In fact, we can only postulate that certain general relativity solutions exist that have the potential to mimic the effect of a discrete time on the vacuum. A bonus would be that such oscillating solutions have no singularity.

To get oscillating solutions, it might be necessary to couple the gravity theory to other theories that have themselves natural oscillating solutions in flat space [†].

Here, to open the way to possible solutions, we wish to indicate a generalisation of the coupling of gravity to a 3-form gauge field, whose static effects related to the cosmological constant have been discussed extensively in the literature [9]. We find this possibility rather elegant from a theoretical point of view, since it might be related to string/branes arguments.

Such an abelian field A_3 has a Maxwell type action, $\int F_4^* F_4$, $F_4 = dA_3$ and accommodates a boundary term in 4 dimensions,

$$S(A, g) = \int d^4x \sqrt{-g} (\partial_{[\mu} A_{\nu\rho\sigma]} \partial^{[\mu} A^{\nu\rho\sigma]}) + \int dA_3 \quad (10)$$

It couples to the gravitational field but it classically carries zero particle degrees of freedom in 4 dimensions. Indeed, if nothing unexpected occurs, for instance an anomaly, the equations of motion and the gauge invariance imply that $F_4 = \text{cte } d^4x$, consistently with the fact that gauge invariance implies that a 3-form has no physical degrees of freedom in 4-dimensions and can only give an energy-momentum tensor proportional to $g_{\mu\nu}$. However, by doing a covariant BRST quantisation, one gets a Feynman type propagation of the unphysical degrees of freedom propagators that is compensated within on-shell amplitudes by that of the ghosts and ghosts of ghosts degrees of freedom. So, the 3-form gauge fields carries potentially some dynamics that an anomaly can reveal, analogously to what the conformal anomaly produces in the Liouville 2d gravity. This makes the existence of a 3-form gauge field even more interesting.

In many valuable papers, it is explained that the 3-form gives a dynamical description for the existence of the static cosmological constant [7][9]. It has been also proposed in [10] that the quantisation of the four-form gauge flux of A_3 can make a variable contribution to the cosmological constant.

We can go a little bit further. Indeed, a “latent” anomaly of the gauge symmetry of the 3-form might enhance the possibility of the wanted high frequency gravitational

[†] For instance [8] and the references therein show the existence of unexpected space oscillating solutions of coupled Einstein $SU(2)$ -Yang–Mills equations that are singularity free.

fields, possibly giving a time-depending value of the cosmological constant. Let us explain a possibility for such an anomaly.

Anomalies may occur in all gauge symmetries of p -form gauge fields according to a simple algebraic classification [11]. They break the gauge symmetries of forms and the way one should count their degrees of freedom, but they can be often compensated by introducing compensating fields, which restore the gauge invariance, but add new degrees of freedom. In our case, we have a 3-form in 4 dimension with curvature $F_4 = dA_3 + \dots$. Then, a (mixed) anomaly can occur if one can construct an invariant 6-form $P_6(A_3, F_4, \dots)$ in $6=4+2$ dimensions, with the algebraic property that $dP_6 = 0$ and P_6 is proportional to the curvature F_4 of A_3 , provided F_4 satisfies a Bianchi identity. Here the terms \dots stand for fields that may couple to the 3-form. To eliminate this anomaly we need other fields to possibly compensate it by a generalisation of the Green–Schwarz mechanism, as in [11]. Such fields can themselves develop anomalies, and we have to be a bit more systematic.

Eventually these various p -form gauge fields will have physical degrees of freedom, and, once they are introduced to ensure that no anomaly can occur in the complete theory, they will enrich the gravity content, and can possibly trigger new favourable oscillating coupled classical solutions beyond the known geometries, at early times, for making realistic our scenario.

So, besides the 3-form gauge field A_3 , we introduce in a minimal scenario a 2-form gauge field \mathcal{B}_2 and a 1-form gauge field \mathcal{A} (or a collection of them, arranged as $U(1)$ fields or as the elements of more complicated Lie algebra), all of them with curvatures involving Chern–Simons couplings, as follows,

$$\mathcal{G}_3 = dB_2 + \mathcal{A} \wedge d\mathcal{A} \quad (11)$$

$$\mathcal{F} = d\mathcal{A}, \quad (12)$$

with the following Bianchi identities, which are non-trivial due to the mixed Chern–Simons coupling in \mathcal{G}_3

$$d\mathcal{G}_3 = \mathcal{F} \wedge \mathcal{F} \quad (13)$$

$$d\mathcal{F} = 0. \quad (14)$$

These fields get coupled to the 3-form A_3 for which we can improve the curvature as

$$F_4 = dA_3 \rightarrow F_4 = dA_3 + \mathcal{A} \wedge \mathcal{G}_3 \quad (15)$$

$$dF_4 = 0 \rightarrow dF_4 = \mathcal{F} \wedge \mathcal{G}_3. \quad (16)$$

By inspection, we find only one possible invariant 6-form depending on the forms $A_3, \mathcal{B}_2, \mathcal{A}$. It is

$$P_6 = \mathcal{F} \wedge \mathcal{F} \wedge \mathcal{F}, \quad (17)$$

but it can be made trivial by a Green–Schwartz mechanism. Indeed,

$$\mathcal{F} \wedge \mathcal{F} \wedge \mathcal{F} = d(\mathcal{A} \wedge \mathcal{F} \wedge \mathcal{F}), \quad (18)$$

so the anomalous QFT effect of $\mathcal{A} \wedge \mathcal{F} \wedge \mathcal{F}$ can be canceled thanks to the Chern–Simons coupling in \mathcal{G} . This gives a local Wess and Zumino counterterm to be possibly added to the possibly anomalous gravity action that interacts with the p -forms. Using descent equations in 4 dimensions, it can be deduced from the six-dimensional non-trivial identity:

$$\mathcal{A} \wedge \mathcal{F} \wedge \mathcal{F} = d(\mathcal{B}_2 \wedge \mathcal{F}) - \mathcal{G}_3 \wedge \mathcal{F} = -d(\mathcal{A} \wedge \mathcal{G}_3). \quad (19)$$

The possible mixed anomaly compensating action is (equivalently) either $\mathcal{A} \wedge \mathcal{G}_3$ or $\mathcal{B}_2 \wedge \mathcal{F}_2$, with an appropriate coefficient. This anomaly compensation mechanism must be triggered if the vacuum can produce pairs of chiral fermions, with a quantised coefficient α for the Chern–Simons terms. Notice that one must then change the definition of F_4 into $F_4 = dA_3 + \mathcal{A} \wedge \mathcal{G}_3$, so the mechanism we were looking for triggering a non trivial gravitational background is subtle. In short, to prevent anomalies, we need the presence of a $U(1)$ gauge field \mathcal{A} and a 2-form \mathcal{B}_2 . Getting a series of forms $\mathcal{A}, \mathcal{B}_2, A_3$ coupled to gravity in 4 dimensions is rather natural, as remnants of an underlying possible and yet unknown geometrical argument. Eventually, the 2-form can be replaced by a scalar field, using duality, and there is no gravitational anomaly because we are in four dimensions.

So we consider the action

$$I_{anomaly \ free} = \int d^4x \sqrt{-g} (R + F_{\mu\nu\rho\sigma} F^{\mu\nu\rho\sigma} + \mathcal{G}_{\mu\nu\rho} G^{\mu\nu\rho} + \mathcal{F}_{\mu\nu} \mathcal{F}^{\mu\nu}) + \beta \int dA_3 + \alpha \int \mathcal{B}_2 \wedge \mathcal{F}, \quad (20)$$

where α and β are numerical coefficients. Whatever is the chiral fermion content of the vacuum, this theory is anomaly free by adequate tuning of the geometric coefficient α .

The role of the 3-form is to give effectively a cosmological constant after its BRST invariant gauge-fixing ; but it also couples locally to the 1-form and 2-form, which are themselves self-coupled. In short, the system is that of a propagating system of a 1-form and a 2-form, also coupled to gravity, whose modes can possibly trigger the high frequency gravitational field that is needed in our scenario for mimicking the effect of a discrete time, with a geometry that involves a cosmological term because of the anomalous 3-form. Because of the Green–Schwartz mechanism, the value of the cosmological constant may vary.

Do we have a time oscillating metrics that satisfies the coupled equations of motions stemming from $I_{anomaly \ free}$? In our scenario, all fields are supposed to oscillate at some frequency, but the coupled 3-form coupling gives perhaps additional horizons analogous to those which occur in DeSitter space. If one wishes a solution that oscillates naturally, one must maybe assuming that the space has the topology of the torus S_3 and impose some periodic boundary conditions; but we can restrict ourself to the case where the oscillations only occur within a bubble of the manifold, whose propagation toward the future becomes the observed horizon from where we are nowadays. Moreover, as explained earlier, one wishes solutions that are non singular.

Eventually a cascade phenomenon of pair creations with masses of the order of magnitude as M_{Planck} might be triggered with a rate as it was roughly estimated in the first part of this paper.

6 Markov (pre-inflation) and Langevin (post-inflation) processes for the Universe

The way we see the pre-inflation epoch resembles a Markov process. It evolves by periodic discrete steps of a given time scale ΔT (we suggested $\Delta T \sim 10^{-15} \tau_{Planck} \sim 10^{-60} s$), with the possibilities of fluctuations that are basically independent of the previous step history. Although we ignore the details of the theory, we proposed that fluctuations are analogous to a Schwinger effect in a powerful and high frequency gravitational coherent state, (coupled to matter fields as e.g. in Eq. (20)). The inflation can be possibly triggered by one of these fluctuations whose effect is to generate black holes with masses of the order of the Planck mass.

It is tempting enough to interpret the successive times $T, T + \Delta T, T + 2\Delta T, \dots$ as the theoretical time of a lattice computation. For an evolution over a very large number of Markov processes, it often makes sense to consider the continuous limit for certain phenomenon with physical time scale $t \gg \mathcal{N}_t \Delta T$, with \mathcal{N}_t extremely large. We can go further. If the corresponding physics has a description in terms of a theory that is continuous in the time t with differential equations involving the differential dt , (in our case, this must occur after the end of the inflation, when the cosmological constant became minuscule), the infinitesimal intervals of physical time dt one uses to physically define the standard QFT path integrals also correspond to a huge number of (ultra-smooth) Markov processes, with duration $dt = \mathcal{N}_{dt} \Delta T$, with $\mathcal{N}_t \gg \mathcal{N}_{dt} \sim \infty$. We thus have the hierarchy for time scales,

$$\Delta T \ll dt \ll t. \quad (21)$$

In fact, we can heuristically say that t is the physical continuous time in Euclidean form that ‘*emerges*’ from the Markov time T .

We call T the microscopic time and t the physical emergent macroscopic time. The later can be the Minkowski time of quantum field theory or that of the space-time of string theory. Strictly speaking t is Euclidean, and we must consider QFT that are compatible with an inverse Wick rotation to define eventually a Minkowski time. Some of the details of the eventual effective smooth time QFT (or string theory) must be related to those of the Markov theory. A spectacular simplification is that in the (very early time) Markov theory, one avoids by definition the classical zero time singularities of gravity coupled theories with a continuous time, simply because of the periodicity of the early time Markov process. In a general Markov process, the nature of (phase) transitions may sometimes exhibits more subtleties than in continuous time transitions, for instance with a beginning, and then a back-up, so that inflation may start, but then quickly abort, or become oscillating at a given rate. But it can equally well evolve with a certain probability to the eventual phase where one has a theory driven by an effective smooth time.

For processes with a macroscopic effective time that is large when it is compared to the microscopic scale ΔT , a Markov equation can be often approximated by a Langevin equation where the stochastic evolution is represented by a random noise $\eta(T, x)$, with

$$\frac{\Delta\Phi(T, x)}{\Delta T} = \frac{\delta I[\Phi]}{\delta\Phi(T, x)} + \eta(T, x) \quad (22)$$

When ΔT is very small, the Langevin equation is continuous,

$$\frac{\partial\Phi(T, x)}{\partial T} = \frac{\delta I[\Phi]}{\delta\Phi(T, x)} + \eta(T, x) \quad (23)$$

Here I is a local action of some fields Φ depending on effective Euclidean coordinates $x = (\vec{x}, t)$. Lorentz invariance is not necessarily ensured at early times but should also emerge at large times. The simplest mathematical hypothesis is that when time is discrete, so does the space, and one has originally a hypercubic symmetry that eventually becomes the Lorentz symmetry.

In the simplest formulation the noise is Gaussian, which means

$$\langle \eta(T, x), \eta(T', x') \rangle \sim \delta(T - T')\delta(x - x') \quad (24)$$

For instance, for the Lagrangian we mentioned, the drift force of the metrics is a combination of the metrics $g_{\mu\nu}$, the Riemann curvature $R_{\mu\nu}$ and the energy momentum tensor $T_{\mu\nu} \sim F^2$ of appropriate p -form gauge fields. To explain the triggering of inflation and simulate the effect of a discrete time, we suggested that if, the p -form gauge fields oscillate strongly enough, then the metrics can also oscillate, yielding a non-singular oscillating geometry that is subjected to an abundant Schwinger effect, creating pairs of black holes. In this description the matter creation is a quantum effect implied by the presence of the Gaussian noise. As we tried to explain, this is a physically appealing description of the triggering of the inflation transition that separates both phases where the time is effectively discrete and where it can be approximated as a continuous and smooth variable.

Equation (23) allows one to compute 5-dimensional Euclidian Green functions in x and T

$$\langle \Phi(x_1, T_1), \dots, \Phi(x_n, T_n) \rangle \quad (25)$$

by first inverting the Langevin equation to get the fields Φ as functions of noises η and then using the definitions of the correlation functions of the noises.

This provides a set of Euclidean correlation functions depending also on T with a wealth of information. We are interested in processes with time scales much bigger than the microscopic pace ΔT . They depend on the emergent Minkowski time x^0 that will be obtained by doing an inverse Wick rotation on t , when the T dependence must disappear by an appropriate limit. We thus assist to a subtle substitution of the Markovian time T into a continuous Minkowski x^0 .

A prescription to get rid of the T dependence to define the correlation functions of the present time 4-dimensional smooth quantum field theory by computing those of the $5 = 4 + 1$ dimensional theory *at equal T* and take the *limit* $T \rightarrow \infty$, namely

$$\langle \Phi(x_1), \dots, \Phi(x_n) \rangle^{\text{continuous Euclidean times } t} \equiv \lim_{T \rightarrow \infty} \langle \Phi(x_1, T), \dots, \Phi(x_n, T) \rangle \quad (26)$$

Eventually, one does Wick rotations generically denoted as $t \rightarrow ix^0$, and the correlators can be used to define S -matrix elements. But these special correlators in (26) are nothing else than those one obtains from the standard Euclidean path integral quantisation of the action I with the equilibrium distribution $\exp -\frac{S}{\hbar}$. In fact, the stochastic time formulation has been initiated in the 60's as a rigorous way to define the path integral in quantum mechanics, and its equivalence theorems (26) for standard quantum field theories have been proven with various degrees of rigour, following the work of Parisi and Wu [12] in the 80's.

We thus claim after this line of reasoning that, in the smooth time (post-inflation) regime, the microscopic time T that clicks by steps of ΔT can be identified as the time of stochastic quantisation, which is in some interpretation the computer time of the standard lattice quantum field approximation for the action I and allows one to obtain the Euclidian Green functions of standard path integral quantisation. In our scenario, the differential dt of the smooth effective time t of quantum field theory can be somehow considered as an agglomerate of truly 'submicroscopic' discrete steps $\Delta T \sim 10^{-60}s$, according to Eq. (21). In fact, dt is the infinitesimal euclidian time elements for the elementary processes in the continuous time standard path integral. In the continuous time regime, the steps ΔT are relatively so small that they are completely invisible and cannot produce observable fluctuations. dt is a sort of averaging of the ΔT over a huge number of relatively smooth iterations. The approximation where one averages over them breaks down in the very early time of the universe, when $t \rightarrow 0$, or, more precisely, when one has physically relevant intervals $t' - t$ of the order of magnitude of $\Delta T \ll \tau_{Planck}$. But at this time, the Markov processes are most favourable to possibly trigger a huge fluctuation that can precisely brings back the universe to a regime where time can be considered as smooth, which physically makes the scheme a consistent one.

When the conditions are such that the Markov processes are invisible, quantum field theory (or its maybe even smoother generalisation string field theory) becomes an excellent and predictive approximation of the world, simply because the Markov processes are approximated by continuous Langevin or Fokker-Planck processes that have a natural description in term of smooth quantum field theory when one averages on huge packages of time steps ΔT . The Langevin equation determines the local action of standard QFT, its drift force gives the equations of motion and its noise drives the quantum fluctuations that bring eventually the universe in the smooth regime. There might be a correspondence between the locality of interactions and the fact that Markov processes involve only neighbour to neighbour interactions. We suggest that the physical picture of a discrete time that undergoes a transition toward a continuous observable time justifies the prescription of selecting observables in the stochastic quantisation as the equal stochastic time correlations functions of the complete theory, when the stochastic time is taken as infinity. As a matter of fact, all my previous attempts to find a symmetry principle for this prescription always failed. Here one finds an unexpected physical argument to justifies the equal stochastic time prescription to extract from a 5-dimensional theory (including the stochastic time) the standard 4-dimensional QFT's that are appropriate to describe the elementary particles in the smooth time limit.

This approach involves an ultra small physical time scale that may represents a physical

ultraviolet cut-off as was advocated for by S. Weinberg in the quantum gravity dominated regime. Here, it represents the submicroscopic scale of Markov processes that are only observable in the phase of the early universe. Such Markov processes build a more general approach than the standard path integral where the stochastic time is only fictitious mathematical time.

We are perfectly conscious of the speculative aspect of this idea of a new physical discrete time building up the continuous time of the low density universe, with a hierarchy as in Eq.(21). In the system of unities $\tau_{Planck} = c = G_N = 1$, one understands that the stochastic time steps define a natural ultraviolet cutoff for all physical objects of the continuous QFT approximation, including the strings. The transition between the epoch when the time variable must be considered as a periodic and discret (a solid) and when it can be considered as smooth (a gaz or a liquid) is in fact the end of the inflation. Hopefully, this new physical ultraviolet cutoff could be used to solve some difficulties posed by the quadratic divergencies of phenomenological QFT's of elementary particles and some of the hierarchy questions.

7 Summary

Let us summarise the rough mechanism we have imagined. When the Universe is at a scale of the order of the Planck length or maybe much smaller, it may function as a resonant cavity for dark energy, that is, it is filled with a non-singular oscillating gravitational coherent state that defines its geometry. This state oscillates at a frequency of the order of magnitude of τ_{Planck}^{-1} or much higher. Such high frequency powerful gravitational coherent states can trigger locally strong enough fluctuations of the vacuum, which may in turn percolate into a transition that reduces drastically the value of the cosmological constant with a probability in time that one can unfortunately only roughly estimate. This microscopic scenario for the beginning of inflation is not in contradiction with the current phenomenological description of the inflation with an effective inflaton field whose evolution is aimed to fit the inflation curve. More research must be done for the existence of non singular geometries with oscillating metrics [‡]. We did some remarks to justify the possible (effective) existence of such an oscillating coherent state by a possible effective coupling of genuine gravity to 1,2,3-forms with Wess and Zumino terms to ensure that the theory is anomaly free.

The alternative hypothesis of a periodic discrete time has the advantage of providing us an attracting theoretical logics for the existence of the strong fluctuation that triggers inflation. The use of a coherent state of dark energy actually mimics the effect of a discrete time in a certain sense, since it gives a periodic behaviour to the vacuum energy momentum tensor. Condensed matter well chosen examples could provide toy models to illustrate this analogy.

The last section suggests that the (physical) Markovian discret time of the pre-inflation

[‡]While writing these notes, I became aware of a recent encouraging article [13] where a simple time dependent 4D-geometry has been exhibited and used for the creation of gravitons, and also [14].

epoch can be perhaps identified with the stochastic time one uses for standard quantisation. Although it is still running in the post-inflation limit, it becomes physically unobservable for all processes such as elementary particles scattering experiments that have gigantic time scales as compared to the duration of the time intervals of the Markov process. In the post-inflation regime the effective time variable *emerges* as a right parameter for time ordering phenomena when one does the inverse Wick rotation of the Euclidean correlators computed by solving the Langevin equations that approximate the Markov processes.

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References

- [1] V. F. Elesin, Sov. Phys. JETP 32, 328 (1971). V. M. Galitskii, V. F. Elesin, and Yu. V. Kopaev, ZhETF Pis. Red. 18, 50 (1973). D. A. Kirshnits and Yu. V. Kopaev, ZhETF Pis. Red. 17, 379 (1973). V. F. Elesin, Yu. V. Kopaev, and R. Kh. Timerov, Zh. Eksp. Teor. Fiz. 65, 2343 (1973). V. M. Galitskii, S. P. Goreslavskii, and V. F. Elesin, Zh. Eksp. Teor. Fiz. 57, 207 (1969).
- [2] *The crossing of defects in ordered media and the topology of 3-manifolds*, V. Ponaru and G. Toulouse, J. Phys. (Paris) 38, 887-95 (203).
- [3] *Superconducting Strings*, E. Witten, Nucl. Phys. B249, 557-592, (1985).
- [4] *Photoinduced superconductivity in semiconductors*, G. Goldstein, C. Aron, C. Chamon, 10.1103, Phys. Rev B 91, 054517 (2015).
- [5] L. Keldysh, Sov. Phys. JETP. 20 (1965); E. Brezin and C. Itzykson, Phys. Rev. D. 2 (1970).
- [6] *Gravitational waves from p-form inflation*, T. Kobayashi, S. Yokoyama, JCAP 0905:004,2009, arXiv:0903.276.
- [7] *Quantum instability of the de Sitter space*, A. M. Polyakov, arXiv [hep-th]1209.4135, and reference therein.
- [8] *Existence of Oscillating Solutions of Einstein SU(2) Yang-Mills Equations*, A. N. Linden, Transactions of the American Mathematical Society, AMS, Vol. 359, No. 11 (Nov., 2007), pp. 5125-5139 .
- [9] *Dynamical neutralization of the cosmological constant* J.D. Brown, C. Teitelboim, Phys.Lett. B195 (1987) 177-182; *Neutralization of the cosmological constant by membrane creation*, J.D. Brown, C. Teitelboim, Nucl.Phys. B297 (1988) 787-836; *Turning*

- the cosmological constant into black holes* , A. Gomberoff, M. Henneaux, C. Teitelboim, hep-th/0111032; *Thermal decay of the cosmological constant into black holes*, A. Gomberoff, M. Henneaux, C. Teitelboim , F. Wilczek, Phys.Rev. D69 (2004), hep-th/0311011, ; *Decay of the cosmological constant: Equivalence of quantum tunneling and thermal activation in two spacetime dimensions* A. Gomberoff, M. Henneaux, C. Teitelboim, Phys.Rev. D71 (2005) 063509, hep-th/0501152, , and reference therein.
- [10] *Quantization of Four-form Fluxes and Dynamical Neutralization of the Cosmological Constant* R. Bousso, J. Polchinski, JHEP 0006:006,2000, arXiv:hep-th/0004134.
 - [11] *Anomaly evanescence and the occurrence of mixed abelian non-abelian gauge symmetries*, L. Baulieu, Phys. Lett. **167B** 56, 1986; *Algebraic construction of gauge invariant theories*, L. Baulieu, Particles and Fields, Cargese, Published in Cargese Summer Inst. 1983, 1, Plenum press.
 - [12] *Perturbation theory without gauge fixing*, G. Parisi, G. Y.-S Wu, Sci. Sinica, **24** 483, (1981).
 - [13] *Graviton Creation by Small Scale Factor Oscillations in an Expanding Universe* E. D. Schiappacasse, L. H. Ford, Phys. Rev. D 94, 084030 (2016), arXiv:1602.08416.
 - [14] *Multiscale spacetimes from first principles* G. Calcagni, arXiv:1609.02776; *Cosmic microwave background and inflation in multi-fractional spacetimes*, G. Calcagni, S. Kuroyanagi, S. Tsujikawa, JCAP 1608 (2016) no.08, arXiv:1606.08449.